Physics Division Research Review

LALP-03-000

The PHENIX Silicon Vertex Tracker Project

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A state of matter not seen in the Universe since the first few microseconds after the Big Bang is the object of study of an international community of physicists at RHIC, the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory. When the Universe was too hot for even protons and neutrons to form, it consisted almost entirely of a soup of truly elementary particles: quarks, and gluons that mediate the force between the quarks. Under the conditions that prevailed for this brief span of time, quarks and gluons were free to roam. As this quark-gluon plasma (QGP) expanded and cooled, the quarks and gluons joined up to form the protons and neutrons that are part of ordinary matter today. Ever since this transition from quark matter to so-called hadronic matter, quarks have been confined to the interior of particles we can observe.

Relativistic Heavy-Ion Collider

The RHIC complex is an accelerator/collider that can produce two counter-rotating beams of gold ions, with each beam accelerated to an energy of 100 GeV (billion electron volts) per nucleon. Thus in a head-on collision between two ions, almost 40,000 GeV of energy is available. For a fleeting instant, conditions in the collision region are thought to be sufficient to form the QGP. These collisions occur at four locations around the 2.4 mile RHIC ring; at each location, experimental apparatus observe/detect the end products of these events. The largest of these experiments is PHENIX (Figure 1).

Besides gold ions, the RHIC complex can also accelerate lighter ions, as well as deuterons (the nuclei of deuterium atoms) and protons. Studies of deuteron-gold and proton-proton collisions are necessary for the proper interpretation of the larger gold-gold events. Finally, RHIC can collide polarized, or spin-oriented, protons—enabling the study of fundamental issues related to proton spin.

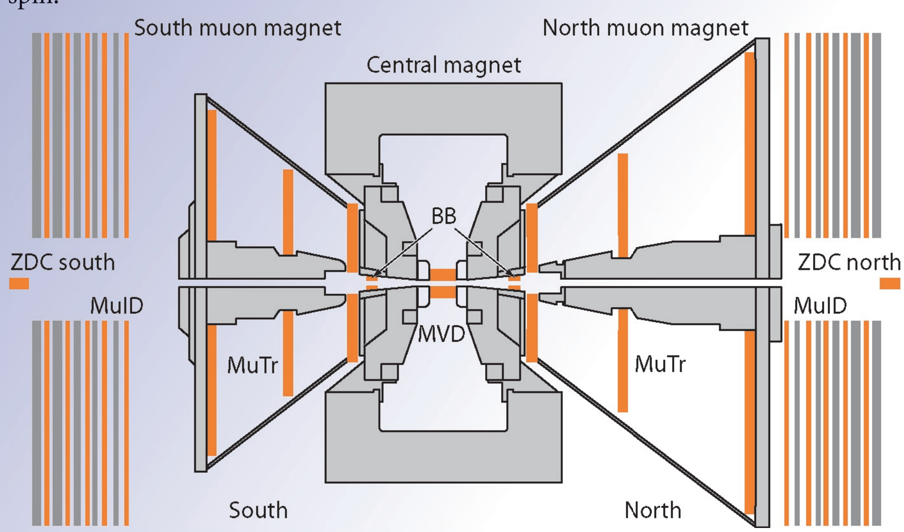

Figure 1. Side view of the PHENIX detector. Beams enter from the left and right and collide in the center. The new silicon vertex tracker will replace the MVD in the center. Note the north and south muon magnets, with three layers of tracking each. The horizontal size is 15 m. (Not shown are detectors wrapping around the collision point on the east and west side of the central magnet.)

PHENIX

The PHENIX experiment is a multipurpose detector of high-energy nuclear interactions, consisting of many different detector types. PHENIX can measure the global distribution of the thousands of particles that are produced in a gold-gold collision. These global measures can be used to determine the 'centrality' of the collision—whether the ions barely grazed each other or if it was a head-on collision. The global observables also tell us, for the most central collisions, that the densities reached are many times the normal nuclear density and that these particles come blasting out at 2/3 the speed of light [at a temperature of 140 to 170 MeV, (equivalent to 1012°C)]. These observations indicate that the conditions for the formation of the QGP indeed exist in these events, but because the bulk of these particles are formed late in the collision, these global measures cannot give us a direct look at the earlier, hotter stages.

Hard Probes

To get a closer glimpse of the QGP, if it is indeed formed early on, the study of so-called hard probes is necessary. These can be particles formed very early in the event and then escape relatively unaffected by the subsequent evolution of the collision. One class of hard probes is the heavy quarks, charm and beauty (the light ones being up, down, and strange). One way to observe these heavy-quark states is to look for one of their characteristic decay modes into muons. PHENIX has a major muon-detection system, largely designed and built by Los Alamos. Data taken in 2003 will yield results on the production of the J/ψ particle, a charm-anticharm bound state. One problem that arises in the study of muons from heavy quarks is that many other processes can produce muons. A property of the heavy-quark mesons (D mesons that contain one charm quark and B mesons that contain one beauty quark) can be exploited in this context: these particles live long enough—before decaying into muons—to travel a significant distance away from the collision point, of order 10s or 100s of microns. Thus the decay muon track will appear to originate from a 'secondary vertex'.

Our strategy, therefore, is to build a tracking detector with sufficient resolution to be sensitive to this decay distance, so that the muons from charm- and beauty-flavored mesons can be separated from the background muon sources.

The Silicon Vertex Tracker

We have embarked on a project to build a silicon vertex tracker that will be installed in the PHENIX detector in the next five years. Figure 2 shows a cutaway drawing of this detector, which wraps around the beam pipe. Beam particles circulate through the pipe in both directions, and collisions occur near the center of the silicon vertex tracker.

The silicon vertex tracker consists of a central section and two endcaps. In the central section, our concentric silicon barrels will locate the event vertex and pick up secondary vertices of tracks roughly transverse to the beam direction. The particles headed towards the muon arms are more parallel to the beam direction, and are tracked by silicon detectors in two sets of disks or lampshades that cover the muon arm acceptance.

Los Alamos has taken on the design and hopes to lead the construction of these silicon endcaps, as well as the responsibility for the overall mechanical structure of the silicon vertex tracker. This structure will be designed and built in collaboration with HYTEC Inc., a local company that has extensive experience in similar projects. The design requirements are stringent, because the detector must be built to close mechanical tolerances, but also be as light as possible. The structure shown in Figure 2 is made of fiber-reinforced polymer and carbon-carbon composite materials, and it meets the design requirements.

To achieve the required track resolution, the silicon in the endcaps will be segmented radially into 50-micron-wide strips, and azimuthally into 96 segments. Strip sizes will range from 50 × 2000 microns nearest the beam pipe to 50 × 11,000 microns at the outside perimeter. We plan on using

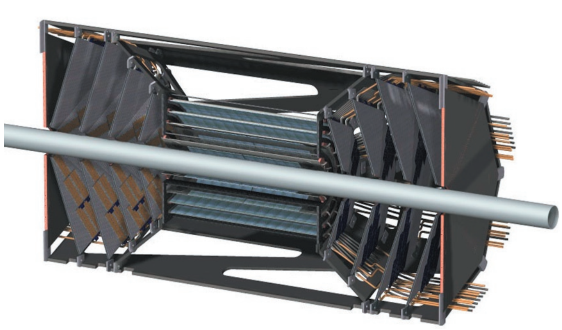

Figure 2. View of one half of the silicon vertex tracker, surrounding the beam pipe. Visible in the center are the four concentric half-cylinders of the central barrel, and at either end the endcap sections, containing four conical disks each. The diameter is 40 cm, length is 80 cm.

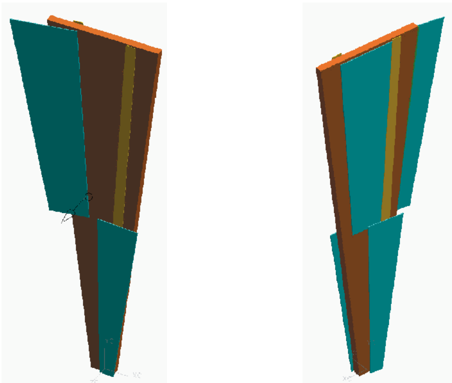

Figure 3. Front (left) and back (right) view of a carbon-composite panel (brown) with four silicon detectors (blue) mounted.

existing technology for the silicon sensors. Silicon pixel designs from the ALICE, ATLAS, or CMS experiments at CERN, the European Laboratory for Particle Physics, can be modified to match the strip sizes that we need. Developing the masks for this effort will be done in concert with the vendors of the CERN sensors, and lengthy and costly research and development (R&D) in this area is not necessary.

A conceptual design for the layout of the silicon disks, or lampshades, is shown in Figures 3 and 4. Carbon-composite panels (brown) carry four silicon detectors each (blue)—two on the front and two on the back. The silicon on the front and back has small overlaps, so that the final assembly will have no gaps in the coverage. A complete lampshade consists of 24 panels.

The silicon detectors are segmented along the long dimension into 50-micron-high strips, which, in turn, are split along the center line. The readout chips (not shown) are placed directly over the centerline and bonded to the strips on both sides. Signals from the smallest silicon strips at the narrow end of these assemblies are carried to the outer perimeter on kapton cables (made of gold).

For the readout electronics, we similarly plan to rely heavily on existing R&D projects. We can adapt chip designs developed at Fermi National Accelerator Laboratory for the proposed BTeV experiment to match our silicon detectors on the input end, and the requirements of the PHENIX data-acquisition system on the output end. Figure 5 shows a chip layout developed from existing components. The left side of the figure shows the logical layout of the chip: two parallel arrays of electronics with signals processed from the outside in. Green is the area where the chip is bonded to the silicon strips. Red is the area reserved for preamplification and discrimination of the signals, orange is pipeline circuitry, and yellow is for digital signal processing.

The bonding locations are staggered, as shown in Figure 5 on the right. This allows us to use a connection technology called bump-bonding, with widely spaced bumps, thereby avoiding technological hurdles associated with dense bump-bonding patterns.

These chips are 13 mm tall. So, 3, 5, or 6 of them need to be chained together lengthwise to service the different silicon detectors. One special feature of the readout chip design is that the chip itself has power and signal bus lines running from the (green) bonding areas on the top and bottom of each chip, allowing them to be chained together. This way, no additional cable is needed to carry communication signals and power from each readout chip to the perimeter of the lampshades. This design simplifies construction and keeps the total mass of the device down.

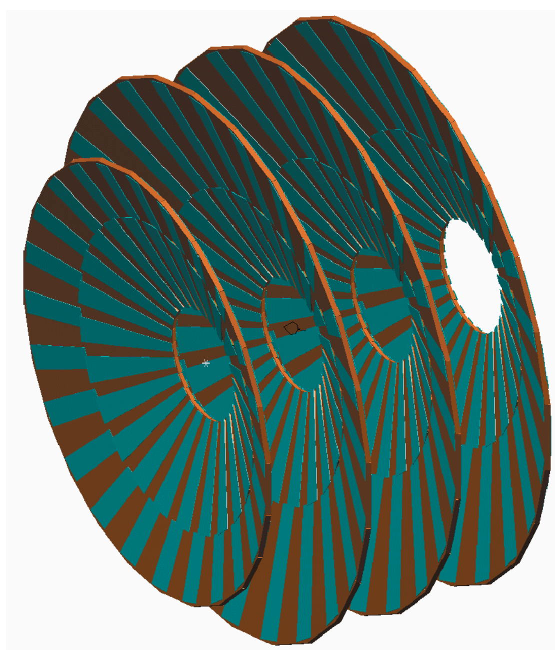

Figure 4. Four lampshades, spaced 6 cm apart, each consisting of 24 panel assemblies, make up one silicon endcap.

Conclusion

We have embarked on a project to extend the physics reach of the PHENIX experiment through the study of charm and beauty signals. Plans call for R&D on the silicon vertex tracker endcaps to continue through 2006, and for construction to proceed for the two years following. The first data taken with the new device are expected in late 2008.

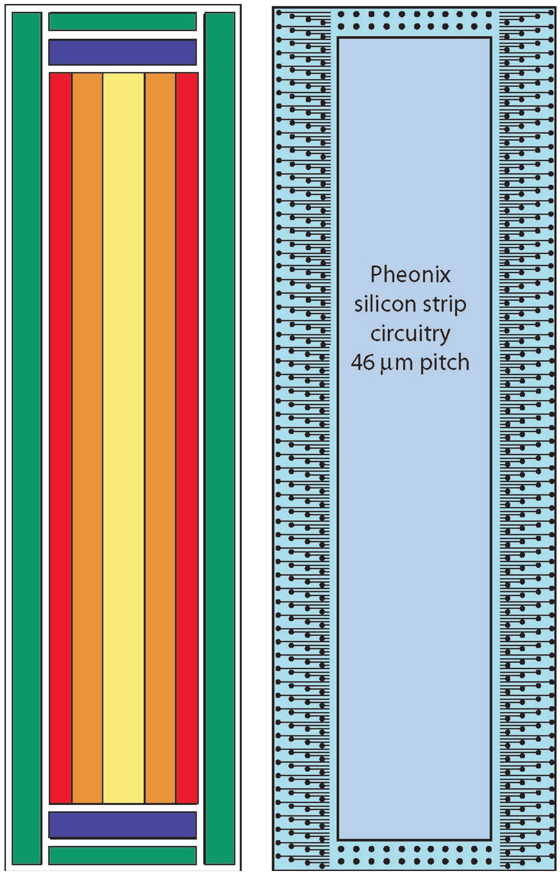

Figure 5. The logical layout of the readout chip is displayed on the left. Green: bonding area; Blue: programming interface; Red: preamp/discriminator; Orange: pipeline; Yellow: digital processing and signal bus. The bump-bond pattern of the chip is displayed on the right. The chip measures 3.8-mm × 13-mm and services 2 × 256 strips.

The Los Alamos National Laboratory silicon vertex tracker effort was supported by LDRD funding. I would like to thank Dave Lee and Pat McGaughey for help in the preparation of this article.

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